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(54) SILANE COATINGS FOR BONDING RUBBER TO METALS

SILANBESCHICHTUNGEN ZUM BINDEN VON GUMMI AN METALLE

REVETEMENTS DE SILANE POUR LIER LE CAOUTCHOUC AUX METAUX

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Description

BACKGROUND OF THE INVENTION

5 Field of the Invention

[0001] The present invention relates to silane coatings for metals. More particularly, the present invention provides silane coatings which not only provide improved adhesion to rubber and other polymers, but also provide corrosion protection (with or without a polymer layer).

10 Description of Related Art

[0002] Most metals are susceptible to corrosion, including the formation of various types of rust. Such corrosion will significantly affect the quality of such metals, as well as that of the products produced therefrom. Although rust and the like may often be removed, such steps are costly and may further diminish the strength of the metal. In addition, when polymer coatings such as paints, adhesives or rubbers are applied to the metals, corrosion may cause a loss of adhesion between the polymer coating and the metal.

[0003] By way of example, metallic coated steel sheet such as galvanized steel is used in many industries, including the automotive, construction and appliance industries. In most cases, the galvanized steel is painted or otherwise coated with a polymer layer to achieve a durable and aesthetically-pleasing product. Galvanized steel, particularly hot-dipped galvanized steel, however, often develops "white rust" during storage and shipment.

[0004] White rust (also called "wet-storage stain") is typically caused by moisture condensation on the surface of galvanized steel which reacts with the zinc coating. On products such as GALVALUME®, the wet-storage stain is black in color ("black rust"). White rust (as well as black rust) is aesthetically unappealing and impairs the ability of the galvanized steel to be painted or otherwise coated with a polymer. Thus, prior to such coating, the surface of the galvanized steel must be pretreated in order to remove the white rust and prevent its reformation beneath the polymer layer. Various methods are currently employed to not only prevent the formation of white rust during shipment and storage, but also to prevent the formation of white rust beneath a polymer coating (e.g., paint).

[0005] In order to prevent white rust on hot-dipped galvanized steel during storage and shipping, the surface of the steel is often passivated by forming a thin chromate film on the surface of the steel. While such chromate coatings do provide resistance to the formation of white rust, chromium is highly toxic and environmentally undesirable. It is also known to employ a phosphate conversion coating in conjunction with a chromate rinse in order to improve paint adherence and provide corrosion protection. It is believed that the chromate rinse covers the pores in the phosphate coating, thereby improving the corrosion resistance and adhesion performance. Once again, however, it is highly desirable to eliminate the use of chromate altogether. Unfortunately, however, the phosphate conversion coating is generally not very effective without the chromate rinse.

[0006] Recently, various techniques for eliminating the use of chromate have been proposed. In particular, various silane coatings have been developed for preventing corrosion of metal substrates. For example, U.S. Patent No. 5,108,793 describes a technique of coating certain metal substrates with an inorganic silicate followed by treating the silicate coating with an organofunctional silane (U.S. Patent No. 5,108,793). U.S. Patent No. 5,292,549 teaches the rinsing of metallic coated steel sheet with a solution containing an organic silane and a crosslinking agent. Other silane coatings are described in U.S. Patent Nos. 5,750,197 and 5,759,629. Furthermore, US Patent numbers 4,210,459 and 4,151,157 disclose polymer composite articles containing polysulfide silicon coupling agents. Hydrolyzable amino silanes having one or more secondary amino groups are used as coupling agents.

[0007] Often, the corrosion protection provided by a particular silane coating will depend upon the identity of the metal substrate itself. In addition, the silane coating must also be compatible with any polymer layer to be applied over the silane coating (such as paints, adhesives or rubbers). For example, while a particular silane coating may provide excellent paint adhesion and corrosion protection, that same silane coating may provide little or no adhesion and to certain rubbers. An example of such a coating is found in WO-A-99 67444, in the name of the present inventors and State of the art in accordance with Art. 54(3) EPC (corresponding EP application 1097259), which discloses a method of preventing corrosion of metals using bis-functional silanes. Thus, it is often necessary to tailor the silane coating to the specific application.

[0008] The silane coatings (or films) known heretofore are typically applied from an aqueous solution wherein the silane(s) are at least partially hydrolyzed. The resulting silane films, however, often contain residual water that can only be driven out by a high temperature heat treatment. Although the films are usually somewhat crosslinked, higher degrees of crosslinking typically require high temperature heat treatment (e.g., 200°C). These silane films are often very thin and fragile, and never completely pore-free or impervious to water. Therefore, corrosion may still occur to some extent when silane coated metals are exposed to a humid environment for a lengthy period of time. While high tem-

perature heat treatment may help alleviate some of these problems, high temperature heat treatment may not always be practical. Thus, there is a need for a silane coating having improved mechanical properties and higher crosslink density, without the need for high temperature processing.

[0009] In addition to corrosion prevention, adhesive bonding between metals and rubber is also of interest. For example, many automobile components (such as tire cords and vibration dampers) rely on adhesive bonding between a metal substrate and a sulfur-cured rubber. Steel tire cords, for example, are typically coated with a thin layer of brass in order to promote adhesion between the underlying steel and the sulfur-cured rubber. In addition, adhesion promoters such as cobalt salt additives, and HRH systems (hexamethylene tetramine, resorcinol and hydrated silica) are also used to further enhance rubber adhesion for tire cords. Solvent-based adhesive systems are used in other applications for bonding metals to sulfur-cured rubbers. Although the performance of the various methods currently employed is adequate, they still suffer from several drawbacks. Cobalt salts, for example, are expensive and pose availability problems, while brass stimulates galvanic corrosion in conjunction with steel. Solvent-based adhesives are flammable and hence hazardous.

[0010] Certain silanes have been found to promote adhesion between a metal substrate and a polymer layer. For example, PCT application, WO-A-99/20705 describes the use of a treatment comprising a mixture of a at least partially hydrolyzed organofunctional and non-organofunctional silane. However, the results are typically system dependent. In other words, the amount of adhesion provided by a particular silane coating typically depends on the metal substrate as well as the polymer layer to be adhered thereto. For example, while certain silane solutions may provide improved adhesion between a metal substrate and a peroxide-cured rubber, these same silane solutions will often not provide the same results for sulfur-cured rubber. Thus, there is also a need for methods of improving adhesion between a metal substrate and a polymer layer, particularly sulfur-cured rubber.

SUMMARY OF THE INVENTION

[0011] It is an object of the present invention to provide silane coatings which provide improved adhesion to rubber, including sulfur-cured and peroxide cured rubber.

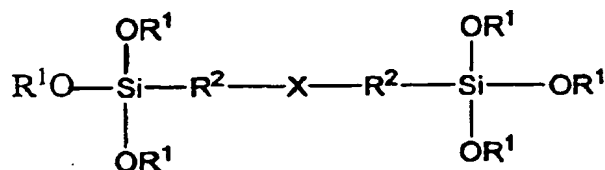
[0012] The foregoing object, in accordance with the present invention, is provided by a method of adhering rubber to a metal substrate, comprising:

(a) applying a coating of a silane composition onto a metal substrate, said silane composition comprising:

- a bis-silyl aminosilane, or the hydrolysate or partial hydrolysate thereof; and
- a bis-silyl polysulfur silane, or the hydrolysate or partial hydrolysate thereof; and

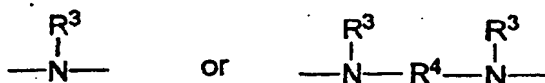
(b) adhering rubber to said coating.

[0013] Particularly preferred bis-silyl aminosilanes include bis-silyl aminosilanes having two trisubstituted silyl groups, wherein the substituents are individually chose from the group consisting of alkoxy aryloxy and acyloxy. Suitable bis-silyl aminosilanes include:



wherein:

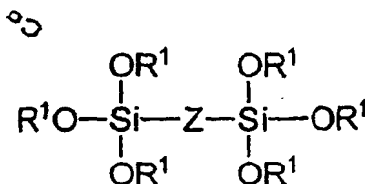
- each R^1 is individually chosen from the group consisting of: C_1 - C_{24} alkyl and C_2
- C_{24} acyl;
- each R^2 is individually chosen from the group consisting of: substituted aliphatic groups, unsubstituted aliphatic groups, substituted aromatic groups, and unsubstituted aromatic groups; and
- X is either:



- 5
- wherein each R³ is individually chosen from the group consisting of: hydrogen, substituted and unsubstituted aliphatic groups, and substituted and unsubstituted aromatic groups; and
 - R⁴ is chosen from the group consisting of: substituted and unsubstituted aliphatic groups, and substituted and unsubstituted aromatic groups.
- 10

[0014] Exemplary bis-silyl aminosilanes include: *bis*-(trimethoxysilylpropyl)amine, *bis*-(triethoxysilylpropyl)amine, *bis*-(triethoxysilylpropyl)ethylene diamine, N-[2-(vinylbenzylamino)ethyl]-3-aminopropyltrimethoxy silane, and aminoethyl-aminopropyltrimethoxy silane.

15 [0015] A bis-silyl polysulfur silane, is included in order to provide improved adhesion to a polymer (such as a paint, an adhesive, or a rubber, including sulfur-cured rubber). Suitable "other" silanes include bis-silyl polysulfur silanes comprising:



20 wherein each R¹ is an alkyl or an acetyl group, and Z is —Q—S_x—Q—, wherein each Q is an aliphatic or aromatic group, and x is an integer of from 2 to 10. An exemplary bis-silyl polysulfur silane is bis-(triethoxysilylpropyl) tetrasulfide.

30 [0016] In the present invention one or more substantially unhydrolyzed bis-silyl aminosilanes are combined with one or more substantially unhydrolyzed bis-silyl polysulfur silanes to provide a silane composition which may be applied to a metal substrate. The resultant silane coating not only provides corrosion protection (even without a polymer coating thereover), but also provides surprisingly improved adhesion to polymers such as paints, adhesives, and rubbers. In particular, the silane coating provides improved adhesion to sulfur-cured rubbers, as well as peroxide-cured rubbers.

35 Uncured (or even cured) rubber compounds are simply applied directly on the silane coating, and then cured in the usual fashion (or, if already cured, the rubber is simply heated while applying pressure). Sulfur-cured and peroxide-cured rubber compounds known to those skilled in the art may be adhered to metal substrates in this manner, using standard rubber curing methods also known to those skilled in the art.

40 [0017] The above mixture of one or more bis-silyl aminosilanes and one or more bis-silyl polysulfur silanes may also be provided as a partially or substantially hydrolyzed silane solution. This hydrolyzed silane solution also provides surprising adhesion to polymers, particularly sulfur-cured and peroxide-cured rubbers.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

45 [0018] In U.S. Patent No. 5,750,197, it was demonstrated that an aqueous solution of a hydrolyzed bis-functional silane (such as 1,2-bis-(trimethoxysilylpropyl) amine) provides corrosion protection. Applicants have now found that mixtures of at least one bis-silyl aminosilane and at least one bis-silyl polysulfur silane provide further improvements in both corrosion protection and polymer adhesion (particularly to sulfur-cured rubber). The silanes do not have to be hydrolyzed, as previously believed, since these silane mixtures provide corrosion protection and enhanced polymer adhesion whether hydrolyzed or unhydrolyzed. In addition, one or more unhydrolyzed aminosilanes may even be applied to a metal substrate alone (with or without the addition of other silanes), since applicants have found that silane coatings applied in this manner will form a dry film which provides corrosion protection. It is believed that secondary or tertiary amino groups in the aminosilane will crosslink, even if the aminosilane has not been hydrolyzed, thereby allowing the formation of a dry film from a one or more unhydrolyzed silanes.

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55 [0019] The solutions and methods of the present invention may be used on a variety of metals, including (but not limited to):

- zinc and zinc alloys, such as titanium-zinc (zinc which has a very small amount of titanium added thereto), zinc-

- nickel alloy (typically about 5% to about 13% nickel content); and zinc-cobalt alloy (typically about 1% cobalt);
- metal substrates having a zinc-containing coating, such as galvanized steel (especially hot dipped galvanized steel ("HDG") and electrogalvanized steel ("EGS")), GALVALUME® (a 55%-Al/43.4%-Zn/1.6% - Si alloy coated sheet steel manufactured and sold, for example, by Bethlehem Steel Corp), GALFAN® (a 5%-Al/95%-Zn alloy coated sheet steel manufactured and sold by Weirton Steel Corp., of Weirton, WV), galvaneal (annealed hot dipped galvanized steel) and similar types of coated metals;
- steel, such as cold rolled steel, carbon steel, hot rolled steel and stainless steel, including steel which has been sandblasted;
- aluminum and aluminum alloys;
- copper and copper alloys, such as brass;
- magnesium alloys; and
- tin and tin alloys, including metal substrates (such as CRS) having tin-containing coatings

[0020] The silane solutions and mixtures of the present invention may be applied to the metal prior to shipment to the end-user, and provide corrosion protection during shipment and storage. The coated metal may be used as is, or, more preferably the end user may apply a polymer layer (such as paint, rubber, or adhesive) directly on top of the silane coating in the usual manner. The silane coatings of the present invention not only provide excellent corrosion protection, but also provide superior adhesion between the metal substrate and the polymer layer. These silane coatings (or films) are also very durable and highly deformable, and therefore provide significant corrosion protection even after deep drawing of the coated metal. The methods and compositions of the present invention are particularly useful for bonding metals to rubber, including sulfur-cured rubber. In fact, the present invention provides improved adhesion between metals and sulfur-cured rubber without the need for cobalt adhesion promoters in the rubber composition.

[0021] The metal substrate can even be sandblasted prior to applying the silane solutions and mixtures of the present invention. For example, a steel substrate (such as hot rolled steel) may be sandblasted prior to application of the solutions of the present invention. Sandblasting typically leaves a high surface roughness as well as surface contaminants, both of which create difficulties when one attempts to apply a coating to sandblasted substrates. The solutions and methods of the present invention, however, allow for the formation of silane coatings on sandblasted substrates.

[0022] The silane compositions of the present invention comprise one or more aminosilanes and one or more bis-silyl polysulfur silanes. The solutions do not require the use or addition of silicates or aluminates, and eliminate the need for phosphate conversion coatings. The silanes in the treatment solution may be substantially unhydrolyzed, partially hydrolyzed, or substantially fully hydrolyzed. As used herein, the term "substantially unhydrolyzed" simply means that the silane(s) are applied either in a pure state (no added solvents) or from a solution which does not include water. However, it is recognized that such silane(s) may absorb some water from the atmosphere, hence the term "substantially unhydrolyzed" (water is not purposefully added to the silane(s)).

[0023] The silane solutions of the present invention may also comprise one or more substantially unhydrolyzed aminosilanes having at least one secondary or tertiary amino group, with or without additional silanes or non-aqueous solvents. Applicants have found that these unhydrolyzed aminosilanes will dry to a hard film at room temperature (typically in 30 minutes or less. The silane coating applied from one or more unhydrolyzed aminosilanes will readily crosslink, and will even crosslink other silanes which are included in the coating. This finding is quite surprising, since conventional wisdom suggests that silanes should only be applied to metals in a hydrolyzed state (i.e., from a solution which includes water).

Hydrolyzed Silane Solutions

[0024] The hydrolyzed silane solutions of the present invention preferably comprise one or more bis-silyl aminosilanes and one or more bis-silyl polysulfur silanes. These hydrolyzed silane solutions also preferably include water (for hydrolysis), and one or more compatible solvents (such as ethanol, methanol, propanol or isopropanol) in order to solubilize the polysulfur silane. The amount of solvent employed will depend upon the concentration of polysulfur silane (s) in the solution, and the solution should therefore include sufficient solvent to solubilize the polysulfur silane(s). The ratio of water to solvent in the silane solution (as applied to the metal substrate, by volume) may be between about 1:99 and about 99:1, more preferably between about 1:1 and about 1:20.

[0025] It is preferred (but not required) that the two silanes (bis-silyl aminosilane and bis-silyl polysulfur silane) are hydrolyzed separately before being mixed with one another to form the silane solution which is applied to the metal substrate. Thus, one or more bis-silyl aminosilanes may be hydrolyzed by mixing the silane(s) with water at the desired concentration. A compatible solvent (such as an alcohol) may be added as desired, however hydrolysis of the bis-silyl aminosilane will generally proceed to completion without an added solvent (and the resulting hydrolyzed silane solution will remain stable). One or more bis-silyl polysulfur silanes may be hydrolyzed in a similar fashion, however a compatible solvent should be included since these silanes are generally not water-soluble. Thus, hydrolysis of the bis-silyl polysulfur

silane(s) may take place in a solution having a water to solvent ratio (by volume) of between about 1:99 and about 99:1, more preferably between about 1:1 and about 1:20.

[0026] As an alternative to employing an organic solvent, the hydrolyzed silanes (particularly the polysulfur silane(s)) may be prepared as an emulsion without a solvent. The silane(s) is simply mixed with water and a suitable surfactant known to those skilled in the art. An emulsified, hydrolyzed solution of a bis-silyl polysulfur silane can be prepared, for example, by mixing a 5% solution of the silane in water along with 0.2% of a surfactant (by volume). Suitable surfactants include, for example, sorbitan fatty acid esters (such as Span 20, available from ICI Surfactants). Once the emulsion of polysulfur silane has been prepared, it may simply be mixed with one or more hydrolyzed bis-silyl aminosilanes as described below and then applied to the metal substrate.

[0027] During hydrolysis, the -OR¹ groups in the bis-silyl aminosilane(s) and the bis-silyl polysulfur silane(s) (as defined below) are replaced by hydroxyl groups. In order to accelerate silane hydrolysis and avoid silane condensation during hydrolysis, the pH may be maintained below about 10, more preferably between about 4 and about 9 (particularly for hydrolysis of the bis-silyl aminosilane). The pH ranges preferred during solution preparation should not be confused with the application pH (i.e., the pH of the silane solution applied to the metal substrate). The pH may be adjusted, for example, by the addition of one or more compatible acids, preferably organic acids such as acetic, formic, propionic or iso-propionic. Sodium hydroxide (or other compatible base) may be used, if needed, to raise the pH of the silane solution. Some silanes provide an acidic pH when mixed with water alone, and for these silanes pH adjustment may not be needed to accelerate silane hydrolysis. The individual silane solutions are preferably stirred for at least 24 hours to ensure complete hydrolysis. In the case of the solution of bis-silyl polysulfur silane(s), hydrolysis may be allowed to proceed for several days (such as 3-4 days, or more) for optimal performance. Once the individual silane solutions have been separately hydrolyzed, they are mixed with one another prior to application on the metal substrate. The hydrolyzed silane mixtures, however, are stable for at least up to 30 days, and therefore need not be used immediately after mixing.

[0028] It should be noted that the various silane concentrations discussed and claimed herein are all defined in terms of the ratio between the amount (by volume) of unhydrolyzed silane(s) employed to prepare the treatment solution (i.e., prior to hydrolyzation), and the total volume of treatment solution components (i.e., aminosilanes, polysulfur silanes, water, optional solvents and optional pH adjusting agents). In the case of aminosilane(s), the concentrations herein (unless otherwise specified) refer to the total amount of unhydrolyzed aminosilanes employed, since multiple aminosilanes may optionally be present. The polysulfur silane(s) concentrations herein are defined in the same manner. During preparation of the individual hydrolyzed silane solutions, the silane concentration in each may vary significantly from the desired total silane concentration in the mixed silane solution (i.e., the solution which is applied to the metal substrate). It is preferred, however, that the silane concentration in the individual hydrolyzed solutions is approximately the same as the desired total silane concentration in the mixed silane solution in order to simplify the final mixing step. In this manner, the final mixed silane solution may be prepared simply by mixing the appropriate ratio of the individual silane solutions.

[0029] As for the concentration of hydrolyzed silanes in the final, mixed silane solution (i.e., the solution applied to the metal substrate) beneficial results will be obtained over a wide range of silane concentrations and ratios. It is preferred, however, that the hydrolyzed solution have at least about 0.1% silanes by volume, wherein this concentration refers to the total concentration of bis-silyl aminosilane(s) and bis-silyl polysulfur silane(s) in the solution. More preferably, the solution has between about 0.1% and about 10% silanes by volume. As for the ratio of bis-silyl aminosilane(s) to bis-silyl polysulfur silane(s) in the hydrolyzed silane solution, a wide range of silane ratios provide beneficial results. Preferably, however the ratio of bis-silyl aminosilane(s) to bis-silyl polysulfur silane(s) is between about 1:99 and about 99:1. More preferably, particularly when the hydrolyzed silane solution is to be used for rubber bonding, this ratio is between about 1:10 and about 10:1. Even more preferably, this ratio is between about 1:3 and about 3:1.

[0030] The term "application pH" refers to the pH of the silane solution when it is applied to the metal surface, and may be the same as, or different from the pH during solution preparation. When used to improve the adhesion of a rubber (particularly sulfur-cured rubber) to a metal, the application pH is preferably between about 4 and about 7, most preferably between about 4 and about 5. The pH of the mixed silane solution may be adjusted in the manner described previously.

[0031] The metal surface to be coated with the mixed hydrolyzed silane solution of the present invention may be solvent and/or alkaline cleaned by techniques well-known to those skilled in the art prior to application of the silane solution. The hydrolyzed silane solution (prepared in the manner described above) is applied to the metal surface (i.e., the sheet is coated with the silane solution) by, for example, dipping the metal into the solution (also referred to as rinsing), spraying the solution onto the surface of the metal, or even brushing or wiping the solution onto the metal surface. Various other application techniques well-known to those skilled in the art may also be used. When the preferred application method of dipping is employed, the duration of dipping is not critical, as it generally does not significantly affect the resulting film thickness. It is merely preferred that whatever application method is used, the contact time should be sufficient to ensure complete coating of the metal (such as 10 seconds or more).

[0032] After coating with the silane solution of the present invention, the metal substrate may simply be air-dried at room temperature. Heated drying is not preferred if the hydrolyzed silane coating is to be used for improving rubber adhesion, since it is preferred that the coating remain only partially crosslinked. While heated drying (or curing) promotes crosslinking, too much crosslinking in the silane coating may prevent sufficient adhesion between a rubber and the metal substrate. Of course the amount of crosslinking can be tailored to suit one's particular needs (such as the desired bond strength between the metal substrate and rubber), and the present invention is therefore not limited to silane coatings dried only at room temperature. Once dried, the treated metal may be shipped to an end-user, or even stored for later use.

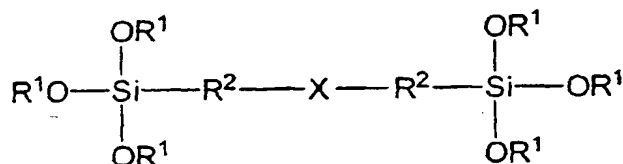
[0033] The coatings applied from hydrolyzed silane solutions of the present invention provide significant corrosion resistance during both shipping and storage. More importantly, this silane coating need not be removed prior to application of a polymer layer on top of the silane coating. Thus, the end-user, such as an automotive manufacturer, may apply a polymer (such as a paint, an adhesive or rubber) directly on top of the silane coating without additional treatment (such as the application of chromates or the use of solvent-based adhesives). The hydrolyzed silane coatings of the present invention not only provide a surprisingly high degree of adhesion to the polymer layer, but also prevent delamination and underpaint corrosion even if a portion of the base metal is exposed to the atmosphere.

[0034] As reported in Application Serial No. 09/356,927, titled *Silane Treatment for Electrocoated Metals*, which names Wim J. van Ooij and Guru P. Sundararajan as inventors, and was filed on July 19, 1999, and the disclosure of which is incorporated herein by way of reference, the hydrolyzed silane solutions of the present invention having both a bis-silyl aminosilane and a bis-silyl polysulfur silane also provide excellent adhesion to paints (particularly electrocoats) and other polymeric adhesives. As also reported therein, and as incorporated herein by way of reference, the hydrolyzed silane solutions of the present application also provide improved corrosion protection, as well as adhesion to other non-rubber polymers (such as paints and adhesives).

[0035] The hydrolyzed silane coatings of the present invention are particularly useful for bonding rubber to various metal substrates, particularly sulfur-cured rubbers such as natural rubber ("NR"), NBR, SBR and EPDM compounds. The uncured rubber compound is merely applied directly on top of the silane coating, and is then cured in the typical fashion (i.e., using the cure conditions required for the particular rubber compound employed). Even previously cured rubber may be adhered to the metals using the silane coatings of the present invention simply by applying the cured rubber compound directly on top of the silane coating and thereafter applying sufficient heat and pressure to adhere the rubber to silane coating (and hence to the metal substrate). Thus, the silane coatings provided by the hydrolyzed silane solutions of the present invention provide improved rubber adhesion, as well as significant corrosion protection. These results are surprising since a coating applied from a solution of a hydrolyzed bis-silyl aminosilane alone provides no adhesion to sulfur-cured rubber. Yet, when a solution comprising the same bis-silyl aminosilane and a hydrolyzed bis-silyl polysulfur silane is used, the resulting adhesion exceeds that provided by the bis-silyl polysulfur silane alone. Previously reported silane coatings which provide improved adhesion to peroxide-cured rubbers, likewise provide no adhesion to sulfur-cured rubbers. An added benefit of the improved adhesion provided by the hydrolyzed silane coatings of the present invention is that the sulfur-cured rubbers may be formulated without cobalt adhesion promoters, since the silane coatings of the present invention improve rubber adhesion without such promoters.

[0036] Since the hydrolyzed silane coatings of the present invention also provide corrosion protection and bonding to polymers other than rubber (such as paint), the present invention has the added benefit of providing silane solutions and methods which may be used in a myriad of applications. Thus, manufacturers need not use one silane solution for corrosion protection, another for paint adhesion, yet another for adhesion to peroxide-cured rubber, and still another for adhesion to sulfur-cured rubber. The hydrolyzed silane solutions of the present invention are suitable for all of these applications on a variety of metals.

[0037] The preferred bis-silyl aminosilanes which may be employed in the present invention have two trisubstituted silyl groups, wherein the substituents are individually chosen from the group consisting of alkoxy, aryloxy and acyloxy. Thus, these bis-silyl aminosilanes have the general structure:



wherein each R¹ is chosen from the group consisting of: C₁ - C₂₄ alkyl (preferably C₁ - C₆ alkyl), and C₂ - C₂₄ acyl (preferably C₂ - C₄ acyl). Each R¹ may be the same or different, however, in the hydrolyzed silane solutions of the

present invention, at least a portion (and preferably all or substantially all) of the R¹ groups are replaced by a hydrogen atom. Preferably, each R¹ is individually chosen from the group consisting of: ethyl, methyl, propyl, iso-propyl, butyl, iso-butyl, sec-butyl, ter-butyl and acetyl.

[0038] Each R² in the aminosilane(s) may be a substituted or unsubstituted aliphatic group, or a substituted or unsubstituted aromatic group, and each R² may be the same or different. Preferably, each R² is chosen from the group consisting of: C₁ - C₁₀ alkylene, C₁ - C₁₀ alkenylene, arylene, and alkylarylene. More preferably, each R² is a C₁ - C₁₀ alkylene (particularly propylene).

[0039] X may be:

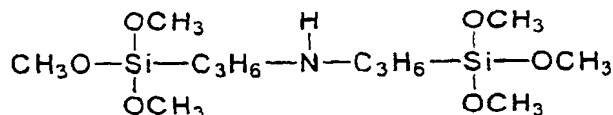


wherein each R³ may be a hydrogen, a substituted or unsubstituted aliphatic group, or a substituted or unsubstituted aromatic group, and each R³ may be the same or different. Preferably, each R³ is chosen from the group consisting of hydrogen, C₁ - C₆ alkyl and C₁ - C₆ alkenyl. More preferably, each R³ is a hydrogen atom.

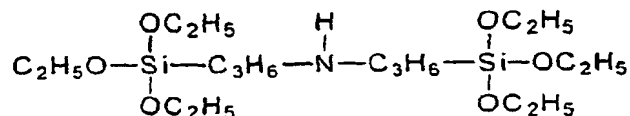
[0040] Finally, R⁴ in the aminosilane(s) may be a substituted or unsubstituted aliphatic group, or a substituted or unsubstituted aromatic group. Preferably, R⁴ is chosen from the group consisting of: C₁ - C₁₀ alkylene, C₁ - C₁₀ alkenylene, arylene, and alkylarylene. More preferably, R⁴ is a C₁ - C₁₀ alkylene (particularly ethylene).

[0041] Exemplary preferred bis-silyl aminosilanes which may be used in the present invention include:

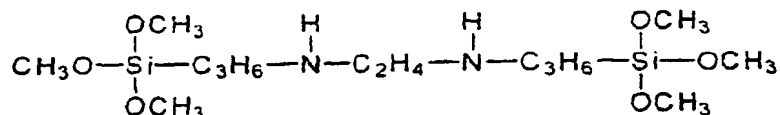
bis-(trimethoxysilylpropyl)amine (which is sold under the tradename A-1170 by Witco):



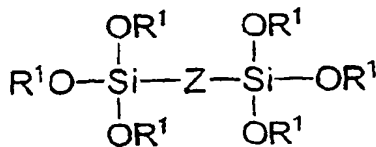
bis-(triethoxysilylpropyl)amine:



and *bis*-(triethoxysilylpropyl)ethylene diamine:

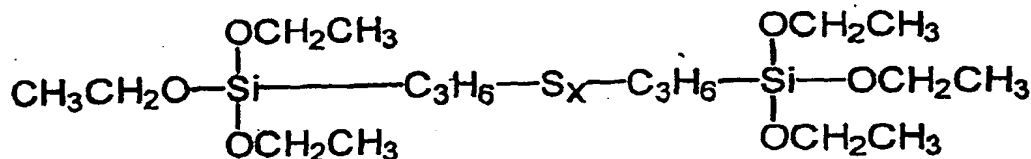


[0042] The preferred bis-silyl polysulfur silanes which may be employed in the present invention include:



wherein each R^1 is as described before. In the hydrolyzed silane solutions of the present invention, at least a portion (and preferably all or substantially all) of the R^1 groups are replaced by a hydrogen atom, Z is $-\text{Q}-\text{S}_x-\text{Q}-$, wherein each Q is an aliphatic (saturated or unsaturated) or aromatic group, and x is an integer of from 2 to 10. Q within the bis-functional polysulfur silane can be the same or different. In a preferred embodiment, each Q is individually chosen from the group consisting of: $\text{C}_1 - \text{C}_6$ alkyl (linear or branched), $\text{C}_1 - \text{C}_6$ alkenyl (linear or branched), $\text{C}_1 - \text{C}_6$ alkyl substituted with one or more amino groups, $\text{C}_1 - \text{C}_6$ alkenyl substituted with one or more amino groups, benzyl, and benzyl substituted with $\text{C}_1 - \text{C}_6$ alkyl.

[0043] Particularly preferred bis-silyl polysulfur silanes include bis-(triethoxysilylpropyl) sulfides having 2 to 10 sulfur atoms. Such compounds have the following formula:



wherein x is an integer of from 2 to 10. One particularly preferred compound is bis-(triethoxysilylpropyl)tetrasulfide (also referred to as bis-(triethoxysilylpropyl) sulfone, or "TESPT"). Commercially-available forms of TESPT (such as A-1289, available from Witco), however, are actually mixtures of bis-(triethoxysilylpropyl) sulfides having 2 to 10 sulfur atoms. In other words, these commercially-available forms of TESPT have a distribution of sulfide chain lengths, with the S_3 and S_4 sulfides predominating. Thus, the scope of the present invention includes hydrolyzed silane solutions containing mixtures of bis-silyl polysulfur silanes in combination with one or more bis-silyl aminosilanes.

Coatings Applied from Unhydrolyzed Silanes

[0044] Applicants have also surprisingly found that unhydrolyzed silanes may be applied directly onto the metal substrate in order to not only provide corrosion protection, but also to provide improved adhesion to polymer layers (such as paints, adhesives, or rubbers). Preferably, at least one bis-silyl aminosilane (such as the bis-silyl aminosilanes described above) is applied to the metal substrate in a substantially unhydrolyzed state (i.e., the R^1 groups are not replaced by a hydrogen atom). One or more additional bis-silyl polysulfur silanes are also mixed with the bis-silyl aminosilane.

[0045] Particularly preferred bis-silyl aminosilanes include the bis-silyl aminosilanes (i.e., $n=2$, $y=0$) described previously, as well as bis-silyl diamino silanes. Suitable bis-silyl diamino silanes include bis (triethoxysilylpropyl)ethylene diamine (a bis-silyl, diamino silane).

[0046] The unhydrolyzed bis-silyl aminosilane(s) is also combined with one or more additional bis-silyl polysulfur silanes, prior to application to the metal substrate. In this fashion, one can tailor the silane coating to the particular application. While one or more bis-silyl aminosilane(s) will provide a curable, corrosion-preventing film, applicants have found that the addition one or more other bis-silyl polysulfur silanes, will not only provide corrosion resistance but also polymer adhesion.

[0047] The present invention comprises a mixture of one or more of the the bis-silyl aminosilanes described previously and one or more bis-silyl polysulfur silanes (as described above), with the silanes in a substantially unhydrolyzed state. The silane(s) whether an aminosilane by itself, or a mixture of one or more aminosilanes and one or more other silanes) may be applied to the metal substrate as a pure silane mixture (i.e., no solvents or water), or may be diluted with a compatible solvent (other than water). Suitable solvents, for example, include, ethanol, methanol, propanol and isopropanol. Diluting the unhydrolyzed silane(s) with a compatible solvent allows the thickness of the silane to be controlled.

[0048] The unhydrolyzed silane(s) are simply coated onto the metal substrate, such as by wiping, dipping or spraying the silane (or silane mixture) onto the metal. Thereafter, the silane coating is dried.

[0049] When the unhydrolyzed silane mixture applied to the metal substrate includes both an aminosilane (such as a bis-silyl aminosilane) and an organofunctional silane (such as a bis-silyl polysulfur silane), the silane coating is preferably dried by heating the coated metal to a temperature of between about 100°C and about 250°C (more preferably to a temperature of between about 100°C and about 160°C, for a period of time sufficient to form a dry film (such as about 10 to about 60 minutes). It should be noted, however, that the amount of drying time will obviously vary with the drying temperature, as well as the nature of the silane coating (e.g., silane concentrations, amount of organic solvent, etc.). Thus, longer periods of time than that specified may be used. As the coating dries, the unhydrolyzed silanes will become partially crosslinked, thereby forming a semi-crosslinked silane coating which not only provides significant corrosion protection, but also improved adhesion to polymers such as paints, adhesives and rubbers (particularly sulfur-cured rubbers). When the unhydrolyzed silane coating is used for polymer adhesion (particularly to sulfur-cured rubber), the silane coated metal should merely be dried for a period of time sufficient to form a dry film (i.e., so that the silane film is semi-crosslinked). When the silane film is intended to provide corrosion protection only, the silane film may be fully crosslinked (or cured) simply by heating the silane coated metal substrate for a longer period of time and/or at a higher temperature. While a fully crosslinked silane film is not desired for polymer adhesion, it will provide significant corrosion protection.

[0050] The unhydrolyzed silane mixtures of the present invention are prepared simply by mixing the silanes with one another in their pure, unhydrolyzed state in the desired ratio. The resulting silane mixture may be diluted with a compatible solvent, if desired. If a solvent is used, the total silane concentration should be at least about 10% (by volume), more preferably at least about 25%.

[0051] As for the ratio of unhydrolyzed bis-silyl aminosilane(s) to other unhydrolyzed bis-silyl polysulfur silane(s), a wide range of silane ratios provide beneficial results. Preferably, however the ratio of bis-silyl aminosilane(s) to other bis silyl polysulfur silanes is between about 1:10 and about 10:1. More preferably, particularly when the unhydrolyzed silane mixture is to be used for rubber bonding, this ratio is between about 1:3 and about 1:1.

[0052] Applicants have found that when the silane compositions include one or more bis-silyl polysulfur silane(s), the resultant silane coating provides superior adhesion to polymers (such as paints, adhesives and rubbers). In fact, the adhesion to sulfur-cured rubbers is even greater than that provided by the hydrolyzed silane solutions of the present invention. Like the hydrolyzed silane solutions discussed previously, the unhydrolyzed silane compositions of the present invention provide unexpectedly high levels of adhesion to a variety of rubber compositions, including sulfur-cured rubber such as high-sulfur rubber systems, low-sulfur rubber systems, EV rubber systems, and semi-EV rubber systems.

[0053] The unhydrolyzed silane compositions of the present invention also provide superior adhesion to other polymer layers, such as various types of paints. Applicants' testing has shown that the silane coatings of the present invention provide improved corrosion protection and improved adhesion to a variety of paints and paint systems, including polyester, polyurethane, epoxy and acrylic paints (or combinations thereof). These paints can be water-borne, solvent-based or even powder paints. Thus, the present application is not limited to silane coatings for improving corrosion protection or rubber adhesion.

[0054] The coatings provided by the unhydrolyzed silane compositions of the present invention are also highly stable. Therefore, a polymer layer may be applied long after the silane coating is established on the metal substrate, and the silane coated metal (without a polymer layer) may be exposed to the environment without significant deleterious effect. Thus, silane coatings provided by the unhydrolyzed silane compositions of the present invention provide a high level of corrosion protection even without a polymer layer thereon, and will still provide improved polymer adhesion even after a lengthy exposure to the environment.

EXAMPLES

Hydrolyzed Silane Solutions

[0055] The examples below demonstrate some of the superior and unexpected results obtained by employing the methods of the present invention. Unless otherwise noted, the various silane solutions described in the following examples were prepared by mixing the indicated silane(s) with water, solvent (ethanol), and acetic acid (if needed to provide the indicated pH during solution preparation). In instances wherein both a bis-silyl aminosilane and a bis-silyl polysulfur silane were employed, the silanes were hydrolyzed separately in a solution of water and solvent, and the hydrolyzed silane solutions were then mixed to form the final silane solution composition indicated. The individual silane solutions were hydrolyzed for at least 24 hours prior to application. The metal substrates were solvent-cleaned, alkaline-cleaned, water rinsed, dried, dipped into the silane solution for approximately 1 minute, and then dried at room temperature.

[0056] In most of the rubber bonding tests which follow, three types of sulfur-cured rubber formulations were used: (1) a typical tire-cord skim compound having a cobalt adhesion promoter; (2) a typical tire-cord skim compound without cobalt adhesion promoter; and (3) a low-sulfur compound used, for example, in engine mount applications. The formulations employed are set forth below (in parts by weight).

Rubber Formulations

[0057]

	Compound 1	Compound 2	Compound 3
NatSyn rubber	100.0	100.0	---
Natural rubber (SMR-5)	---	---	100.0
Zinc Oxide	10.0	10.0	3.0
Stearic acid	1.2	1.2	2.0
Carbon black	60.0 (N326)	60.0 (N326)	50.0 (N330)
Santoflex 13	1.0	1.0	2.0
Sundex 790	---	---	10.0
Cobalt naphthenate 10%	2.0	---	---
Vulkacit DZ	0.5	0.5	---
PVI	0.2	0.2	---
Insoluble sulfur (20% oil)	7.0	7.0	---
Microcrystalline wax	---	---	2.0
CBS	---	---	1.4
Sulfur	---	---	2.5

Example 1

[0058] The following table provides adhesion results using hydrolyzed silane solutions on cold rolled steel ("CRS"). For each of the silane solutions, the indicated concentration (by volume) of the silane was mixed with alcohol (methanol or ethanol) and an amount of water equivalent to the silane concentration. For example, a 5% A1170 solution was prepared by mixing 5% A1170, 5% water and 90% ethanol (by volume). The pH was adjusted to the indicated amount by adding acetic acid as needed. The silane solution was stirred for at least 24 hours in order to complete hydrolysis. For mixtures of A1170 and A1289, the silanes were separately hydrolyzed in the same manner (5% silane, 5% water and 90% alcohol). After at least 24 hours of hydrolysis, the two silane solutions were mixed together to provide the indicated ratio of A1170:A1289, with the total silane concentration in the mixed silane solutions being 5% in all cases.

[0059] CRS panels were ultrasonically cleaned in acetone, hexane and methanol. The panels were then alkaline cleaned in the usual manner, rinsed in deionized water, and blow-dried with hot air. The panels were then dipped into the silane solution for 30-45 seconds, and thereafter dried.

[0060] In order to evaluate the adhesion to rubber provided by the silane coatings, a layer of the specified uncured rubber composition was sandwiched between two silane coated panels. One half of each metal panel was shielded from the rubber by a Mylar film in order to prevent bonding in that region. The composite article was then cured in a hydraulic press at 160°C (8 minutes for Rubber Compound 1, 11 minutes for Rubber Compound 2, and 5 minutes for Rubber Compound 3). After curing, adhesion strength was measured by pulling portion of each metal panel not bonded to the cured rubber (because of the Mylar film) away from the rubber in opposite directions using an Instron Tensile Tester (Instron 4465) at a jaw speed of 2.54 cm/min. The force required to separate the composite is shown in the table, along with the failure mode. A "100% interface" failure mode means that the metal peeled away from the rubber, while "cohesive failure" means that the rubber itself failed before the metal to rubber bond.

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Silane, Conc.	pH	Rubber compound	Instron	Failure mode
None	---	Compound 2	0 N	100% Interface
VS, 5%	4.0	Compound 2	0 N	100% Interface
BTSE, 5%	4.0	Compound 2	0 N	100% Interface
2% BTSE, 5% VS**	4.0	Compound 2	0 N	100% Interface
A1170, 5%	4.0	Compound 2	0 N	100% Interface
A1289, 2%	7.9	Compound 2	122 ± 43 N	100% Interface
A1289, 2%	2.9	Compound 2	160 ± 150 N	100% Interface
A1289, 2%	5.0	Compound 2	115 ± 50 N	100% Interface
A1289, 1%	6.5	Compound 2	120 ± 79 N	100% Interface
A1289, 0.5%	6.0	Compound 2	174 ± 15 N	100% Interface
A1289, 5%	4.0	Compound 2	350 ± 20 N	100% Interface
A1170:A1289 = 3:1	6.9	Compound 2	233 ± 20 N	100% Interface
A1170:A1289 = 3:1	4.4	Compound 2	161 ± 88 N	100% Interface
A1170:A1289 = 1:1	6.95	Compound 2	262 ± 13 N	100% Interface
A1170:A1289 = 1:1	4.5	Compound 2	272 ± 18 N	100% Interface
A1170:A1289 = 1:3	7.1	Compound 2	264 ± 57 N	100% Interface
A1170:A1289 = 1:3	4.4	Compound 2	692 ± 50 N	>80% Cohesive
A1170:A1289 = 1:3	4.4	Compound 2	220 ± 78 N	50% Cohesive
A1170:A1289 = 1:3*	4.2	Compound 2	238 ± 31 N	100% Interface
A1170:A1289 = 1:9	4.4	Compound 2	438 ± 57 N	50% Cohesive
A1170:A1289 = 1:9	4.4	Compound 2	179 ± 18 N	100% Interface
A1170:A1289 = 1:4	4.2	Compound 2	327 ± 16 N	50% Cohesive
A1170:A1289 = 1:19	4.38	Compound 2	184 ± 10 N	100% Interface
A1289, 2%	6.5	Compound 1	212 ± 30 N	100% Interface
A1289, 5%	6.5	Compound 1	267 ± 30 N	100% Interface
A1170:A1289 = 1:3	4.25	Compound 1	215 ± 11 N	100% Interface
A1170:A1289 = 1:3	4.4	Compound 3	271 ± 7 N	100% Interface
A1170:A1289 = 1:9	4.4	Compound 3	246 ± 17 N	100% Interface
A1170:A1289 = 1:19	4.2	Compound 3	257 ± 60 N	100% Interface

* A-1170 solution was one week old

** two-step treatment method

VS = vinyltrimethoxysilane

BTSE = 1,2-bis-(triethoxysilyl)ethane

A-1170 = bis-(trimethoxysilylpropyl) amine

A-1289 = bis-(triethoxysilylpropyl) tetrasulfide

The wide discrepancies in the data reported above are due, in part, to the nature of the method of measuring adhesion. For example, many of the samples bent during testing, thereby calling into question the accuracy of adhesion force

measurements for such samples. Therefore, the mode of failure provides a more accurate representation of rubber adhesion.

[0061] As indicated by the above results, mixtures of hydrolyzed A1170 and A1289 provided adhesion which was surprisingly superior to that provided by either silane alone. In fact, a hydrolyzed solution of A1170 provided no adhesion at all, yet even a small addition of A1170 to a hydrolyzed solution of A1289 improves adhesion. Other hydrolyzed silane solutions provided no adhesion to the sulfur-cured rubber, including the two-step BTSE / VS treatment which has previously been shown to provide excellent adhesion to peroxide-cured rubbers. The above results also indicate that the hydrolyzed silane mixtures of the present invention allow for the elimination of cobalt adhesion promoters, since the silane mixtures of the present invention provide better adhesion when the cobalt adhesion promoter is not used.

Example 2

[0062] Panels of electrogalvanized steel ("EGS") were tested in the same manner as in Example 1, and the results are provided below.

Silane, Conc.	pH	Rubber compound	Instron	Failure mode
A1170, 5%	8.5	Compound 2	0 N	100% Interface
A1289, 5%	6.5	Compound 2	120 \pm 30 N	100% Interface
A1170:A1289 = 3:1	6.9	Compound 2	121 \pm 61 N	100% Interface
A1170:A1289 = 1:1	6.9	Compound 2	91 \pm 13 N	100% Interface
A1170:A1289 = 1:3	7.1	Compound 2	72 \pm 35 N	100% Interface

As noted from the above table, the addition of hydrolyzed A1170 to hydrolyzed A1289 solutions does not significantly affect adhesion performance, even though hydrolyzed A1170 by itself provides no adhesion. However, the addition of A1170 during the period of time will provide greater corrosion protection, particularly during metal shipment or storage between application of the silane coating and rubber bonding.

Example 3

[0063] Panels of tin-coated CRS were tested in the same manner as in Example 1, and the results are provided below.

Silane, Conc.	pH	Rubber compound	Instron	Failure mode
A1170:A1289 = 1:3	4.25	Compound 1	227 \pm 18 N	100% Interface
A1170:A1289 = 1:9	4.4	Compound 1	173 \pm 44 N	100% Interface
A1170:A1289 = 1:19	4.38	Compound 1	164 \pm 4 N	100% Interface

Unhydrolyzed Silanes

[0064] In the next set of examples, unhydrolyzed silane compositions were employed. Unless otherwise noted, all of the silane coatings were applied from pure silanes (either pure A1170, or a mixture consisting only of A1170 and A1289 in the indicated ratio). After the silanes were mixed with one another, the resultant silane mixture was wiped onto the metal (which had been cleaned in the manner described previously) using a paper towel. Unless otherwise noted, the silane coating applied in this manner was then dried for one hour at 150°C. Thereafter, the rubber composition was bonded to the silane coated metal in the manner described previously.

Example 4

[0065] Panels of 63/37 brass were coated with unhydrolyzed silanes, and rubber adhesion was tested in the same manner as in Example 1:

Silane, Conc.		Rubber compound	Instron	Failure mode
Blank		Compound 1	800 ± 50 N	100% Cohesive
A1170:A1289 = 1:3		Compound 1	685 ± 81 N	75% Cohesive
Blank		Compound 2	450 ± 30 N	60% Cohesive
A1170:A1289 = 1:3		Compound 2	926 ± 71 N	90% Cohesive
Blank		Compound 3	380 ± 33 N	100% interface
A1170:A1289 = 1:3		Compound 3	679 ± 49 N	70% Cohesive

Although sulfur-cured rubber having a cobalt adhesion promoter adheres well to uncoated 63/37 brass, the unhydrolyzed A1170/A1289 mixture provided excellent adhesion to all three rubber formulations (with or without the cobalt adhesion promoter). Thus, the silane mixtures of the present invention allows for the elimination of the cobalt adhesion promoter, while also providing improved corrosion protection.

Example 5

[0066] Panels of Alloy 360 brass and Alloy 260 brass were coated with unhydrolyzed silanes, and adhered to a rubber composition in the same manner as in Example 4. Rubber adhesion was then tested in accordance with ASTM D429(B), and the results are provided below.

Metal	Silane, Conc.	Rubber compound	Adhesion
Alloy 360 brass	Blank	Compound 1	0 N/mm
	Blank	Compound 2	0 N/mm
	A1170:A1289 = 1:3	Compound 2	10.46 ± 1.6 N/mm
Alloy 260 brass	Blank	Compound 1	12.13 ± 3.0 N/mm
	Blank	Compound 2	10.23 ± 3.6 N/mm
	A1170:A1289 = 1:3	Compound 2	11.14 ± 1.4 N/mm

As the above table indicates, the unhydrolyzed silane mixtures of the present invention provide excellent rubber adhesion on a variety of brass alloys, including Alloy 360 brass (which will not adhere to sulfur-cured rubber).

Example 6

[0067] Panels of CRS were coated with unhydrolyzed silanes, and rubber adhesion was tested in the same manner as in Example 4:

Silane, Conc.	Rubber compound	Instron	Failure mode
Blank	Compound 2	0 N	100% Interface
A1170:A1289 = 1:3*	Compound 2	325 ± 36 N	10% Cohesive
A1170:A1289 = 1:3**	Compound 2	752 ± 124 N	2 samples ≈ 80% cohesive failure, 1 sample ≈ 50% cohesive failure
A1170:A1289 = 1:3**	Compound 2	476 ± 296 N	1 sample ≈ 80% cohesive failure, 2 samples ≈ 30% cohesive failure
A1170:A1289 = 1:1*	Compound 2	284 ± 34 N	10% Cohesive
A1170:A1289 = 1:1**	Compound 2	398 ± 163 N	≈ 20% cohesive failure
A1170:A1289 = 1:1**	Compound 2	261 ± 39 N	10% cohesive failure
Blank	Compound 3	0 N	100% Interface
A1170:A1289 = 1:3**	Compound 3	209 ± 29 N	100% Interface

* silane mixture had aged for 2 days

** silane mixture had aged for one week

Once again the large discrepancies in the adhesion values noted in the above table are due, in part, to the nature of the test employed. Therefore, the mode of failure is considered by the Applicants to be more significant. The above results demonstrate that unhydrolyzed mixtures of A1170 and A1289 provide even greater rubber adhesion than the hydrolyzed silane solutions of the present invention. This is surprising since conventional wisdom teaches that silanes should be applied to metals in a hydrolyzed state, rather than substantially unhydrolyzed. In addition, applicants have found that while unhydrolyzed A1289 alone will not form a dry film, when combined with unhydrolyzed A1170 it provides a superior, crosslinked silane coating. This highly crosslinked silane coating not only provides improved adhesion to rubbers and other polymers (such as paint), it also provides excellent corrosion protection (even without a polymer layer on top of the silane coating).

Example 7

[0068] Panels of EGS were coated with unhydrolyzed silanes, and rubber adhesion was tested in the same manner as in Example 4:

Silane, Conc.	Rubber compound	Instron	Failure mode
Blank	Compound 2	0 N	100% Interface
A1170:A1289 = 1:3*	Compound 2	567 ± 200 N	2 samples ≈ 80% cohesive failure, 1 sample ≈ 30% cohesive failure
A1170:A1289 = 1:3**	Compound 2	629 ± 132 N	1 sample > 80% cohesive failure, 2 samples ≈ 40% cohesive failure
A1170:A1289 = 1:3**	Compound 2	422 ± 73 N	20% cohesive failure
A1170:A1289 = 1:1*	Compound 2	640 ± 70 N	85-90% Cohesive
A1170:A1289 = 1:1**	Compound 2	606 ± 124 N	≈ 40-50% cohesive failure
A1170:A1289 = 1:1**	Compound 2	433 ± 245 N	1 sample ≈ 80% cohesive failure, 2 samples ≈ 20% cohesive failure
Blank	Compound 3	0 N	100% Interface

* silane mixture had aged for 2 days

** silane mixture had aged for one week

(continued)

Silane, Conc.	Rubber compound	Instron	Failure mode
A1170:A1289 = 1:3**	Compound 3	534 ± 157 N	2 sample ≈ 60% cohesive failure, 1 sample ≈ 40% cohesive failure
A1170:A1289 = 1:1**	Compound 3	391 ± 135 N	≈ 30% cohesive failure

** silane mixture had aged for one week

Example 8

[0069] Panels of NedZinc (a zinc-titanium alloy) were coated with unhydrolyzed silanes, and rubber adhesion was tested in the same manner as in Example 4:

Silane, Conc.	Rubber compound	Instron	Failure mode
A1170:A1289 = 1:3*	Compound 2	434 ± 131 N	50% cohesive failure

* silane mixture had aged for 2 days

Example 9

[0070] In order to evaluate the stability of aluminum to rubber bonding using unhydrolyzed silanes, panels of aluminum were coated with unhydrolyzed silanes. SBR, NBR and EPDM rubber compositions were used in this test, and the rubber formulations were as follows:

	SBR	NBR
SBR 1500	100.0	---
NBR	---	100.0
Zinc Oxide	5.0	5.0
Stearic acid	2.0	2.0
Processing Aid	4.0	---
DOP	---	10.0
Carbon black	50.0 (N330)	30.0 (N770) 70.0 (N550)
MBTS	1.0	---
TMTD	0.5	2.0
Sulfur	2.0	1.5
CBS	---	1.0

	EPDM 1	EPDM 2
Vistalon 2504	100.0	---
Vistalon 5630/5300	---	50.0/50.0
Zinc Oxide	5.0	5.0
Stearic acid	1.0	1.0
Aromatic Oil	35.0	---

(continued)

	EPDM 1	EPDM 2
Naphthenic Oil	---	60.0
Carbon black	60.0 (N990) 70.0 (N550)	75.0 (N990) 75.0 (N550)
TMTD	0.6	2.0
MBTS	1.0	---
CBS	---	2.0
ZDBC	2.0	---
DTDM	---	2.0
Sulfur	2.0	0.3

The cured rubber compositions were applied to silane coated panels, and then cured by standard curing conditions. Rubber adhesion was tested according to ISO 813 (equivalent to ASTM D4298), and was reported qualitatively. The panels were tested immediately after curing, and after the specified exposure time in water at 100°C.

Silane, Conc.	Rubber compound	Exposure Time in Water, 100°C				
		Initial	24 hr	48 hr	72 hr	168 hr
A1170:A1289 = 1:3	EPDM 1	3.8	3.5	3.5	3.5	3.5
A1170:A1269 = 1:3	EPDM 2	3.5	3.4	3.4	3.4	3.0
A1170:A1289 = 1:3	SBR	4	4	3.8	3.8	3.8
A1170:A1289 = 1:3	NBR	4	4	4	4	4
4 = ≥ 95% rubber (i.e., cohesive) failure 3 = high strength, partial rupture, >10% rubber failure 2 = medium strength peel - interfacial rupture 1 = low strength peel 0 = no bond						

Example 10

[0071] Various other metals were adhered to rubber in the same manner as Example 9, using a mixture of unhydrolyzed A1170 and unhydrolyzed A1289 (1:3 ratio). Rubber adhesion was evaluated according to ISO 813, and the adhesion results are reported below (in N/mm).

Metal	Rubber compound	Exposure Time in Water, 100°C			
		Initial	72 hrs	168 hrs	336 hrs
304 Stainless Steel	EPDM 1	6.1N/mm 8.0	7.1	6.1 8.5	8.1
1010 Carbon Steel	EPDM 1	8.3 6.3	6.0	7.4 5.1	4.9
Aluminum	EPDM 1	5.3	5.9	6.1	
70/30 Brass	EPDM 1	7.9	6.5	6.8	
304 Stainless Steel	NBR	12.9	9.9	11.4	
1010 Carbon Steel	NBR	14.6	10.4	15.3	
Aluminum	NBR	8.6	7.8	10.4	

(continued)

Metal	Rubber compound	Exposure Time in Water, 100°C			
		Initial	72 hrs	168 hrs	336 hrs
70/30 Brass	NBR	15.1	9.4	8.7	
304 Stainless Steel	EPDM 3	8.9	8.5	5.6	
1010 Carbon Steel	NBR 2	20.6	10.3	9.4	
"EPDM 3" and "NBR 2" were standard peroxide-cured EPDM and NBR rubbers, respectively.					

Example 11

[0072] In order to examine the effect of silane aging, low carbon steel (SAE C-1018) was bonded to rubber in the same manner as in Example 10 (unhydrolyzed silanes, A1170:A1289 = 1:3). Rubber adhesion was also tested in accordance with ASTM D429B.

Age of Silane Mixture	Peel Strength, N/mm	Mode of Failure
Fresh	11.7 ± 1.5	100% cohesive
Aged 2.5 weeks	11.2 ± 1.3	100% cohesive
Aged 8 weeks	13.0 ± 0.8	100% cohesive

Example 12

[0073] In order to examine the effect of silane concentration in the unhydrolyzed systems of the present invention, CRS was bonded to rubber in the same manner as in Example 10 (unhydrolyzed silanes, A1170:A1289 = 1:3). Rubber adhesion was also tested in the same manner as in Example 11.

Silane, Conc.	Rubber compound	Adhesion Strength	Failure mode
100% Silanes (A1170:A1289 = 1:3)	Compound 2	11.7 ± 1.5 N/mm	100% Cohesive
50% Silanes in Ethanol	Compound 2	9.5 ± 1.7 N/mm	100% Cohesive
25% Silanes in Ethanol	Compound 2	10.4 ± 4.4 N/mm	90% Cohesive
100% Silanes (A1170:A1289 = 1:3)	Compound 3	10.2 ± 2.3 N/mm	80% Cohesive

As noted above, the unhydrolyzed silane mixtures of the present invention may be applied as pure silanes (i.e., no solvents), or with significant quantities of non-aqueous solvents (such as ethanol or methanol).

Claims

1. A method of adhering rubber to a metal substrate, comprising:

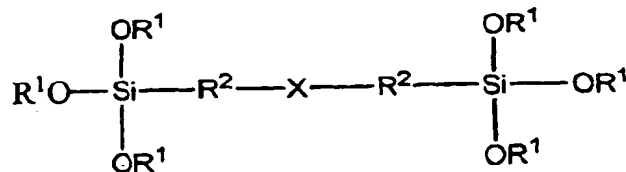
(a) applying a coating of a silane composition onto a metal substrate, said silane composition comprising:

- a bis-silyl aminosilane, or the hydrolysate or partial hydrolysate thereof; and
- a bis-silyl polysulfur silane, or the hydrolysate or partial hydrolysate thereof; and

(b) adhering rubber to said coating.

2. The method of claim 1, wherein said bis-silyl aminosilane comprises an aminosilane having two trisubstituted silyl groups, wherein the substituents are individually chosen from the group consisting of alkoxy, aryloxy and acyloxy.

3. The method of claim 2, wherein said bis-silyl aminosilane comprises:



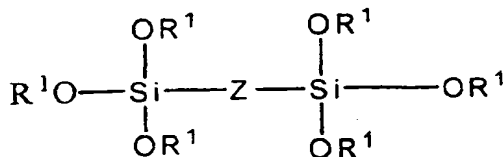
wherein:

- each R¹ is individually chosen from the group consisting of: C₁ - C₂₄ alkyl and C₂ - C₂₄ acyl
- each R² is individually chosen from the group consisting of: substituted aliphatic groups, unsubstituted aliphatic groups, substituted aromatic groups, and unsubstituted aromatic group; and
- X is either:



- wherein each R³ is individually chosen from the group consisting of: hydrogen, substituted and unsubstituted aliphatic groups, and substituted and unsubstituted aromatic groups; and
- R⁴ is chosen from the group consisting of: substituted and unsubstituted aliphatic groups, and substituted and unsubstituted aromatic groups.

4. The method of claim 3, wherein each R¹ is individually chosen from the group consisting of: ethyl methyl, propyl, iso-propyl, butyl, iso-butyl, sec-butyl, ter-butyl and acetyl.
5. The method of claim 3, wherein X is chosen from the group consisting of: a C-Si bond, C₁ - C₆ alkylene, C₁ - C₆ alkenylene, C₁ - C₆ alkylene substituted with at least one amino group, C₁ - C₆ alkenylene substituted with at least one amino group, arylene, and alkylarylene.
6. The method of claim 3, wherein each R² is individually chosen from the group consisting of: hydrogen, ethyl, methyl, propyl, iso-propyl, butyl, iso-butyl, sec-butyl, ter-butyl and acetyl.
7. The method of claim 1, wherein said bis-silyl aminosilane is chosen from the group consisting of: bis-(trimethoxysilylpropyl)amino, bis-(triethoxysilylpropyl)amine, and bis-(triethoxysilylpropyl)ethylene diamine.
8. The method of claim 1, wherein said bis-silyl polysulfur silane comprises:



wherein each R¹ is an alkyl or an acetyl group, and Z is —Q—S_x—Q— wherein each Q is an aliphatic or aromatic group, and x is an integer of from 2 to 10.

9. The method of claim 8, wherein each R¹ is individually chosen from the group consisting of: ethyl, methyl, propyl, iso-propyl, butyl, iso-butyl, sec-butyl, ter-butyl and acetyl.

10. The method of claim 8, wherein each Q is individually chosen from the group consisting of: C₁ - C₆ alkyl (linear or branched), C₁ - C₆ alkenyl (linear or branched), C₁ - C₆ alkyl substituted with one or more amino groups, C₁ - C₆ alkenyl substituted with one or more amino groups, benzyl, and benzyl substituted with C₁ - C₆ alkyl.

11. The method of claim 1, wherein said at least one bis-silyl polysulfur silane comprises a bis-(triethoxysilylpropyl) sulfide having 2 to 10 sulfur atoms.

12. The method of claim 11, wherein said at least one bis-silyl polysulfur silane comprises bis-(triethoxysilylpropyl) tetrasulfide.

13. The method of claim 1, wherein said metal substrate is chosen from the group consisting of:

- zinc and zinc alloys;
- metal substrates having a zinc-containing coating;
- steel;
- aluminum and aluminum alloys;
- copper and copper alloys;
- magnesium alloys;
- tin and tin alloys; and
- metal substrates having tin-containing coatings

14. The method of claim 1, wherein the silanes in said silane composition are substantially unhydrolyzed.

15. The method of claim 14, wherein the ratio of bis-silyl aminosilanes of bis-silyl polysulfur silanes in said silane composition is between 1:10 and 10:1.

16. The method of claim 14, wherein said silane composition further comprises a non-aqueous solvent.

17. The method of claim 1, wherein said silane composition consists essentially of said at least one substantially unhydrolyzed bis-silyl aminosilane and said at least one substantially unhydrolyzed bis-silyl polysulfur silane.

18. The method of claim 1, wherein the silanes in said silane composition are at least partially hydrolyzed.

19. The method of claim 18, wherein the ratio of bis-silyl aminosilanes to bis-silyl polysulfur silanes in said silane composition is between 1:10 and 10:1.

20. The method of claim 19, wherein said silane composition further comprises water and a solvent.

21. The method of claim 20, wherein the ratio of water to solvent in said silane composition is between 1:1 and 1:20.

22. The method of claim 18, wherein the pH of said silane composition is between 4 and 7.

23. The method of claim 1, wherein said rubber comprises a sulfur-cured rubber.

24. The method of claim 23, wherein said step of adhering said sulfur-cured rubber comprises applying an uncured rubber compound directly onto said silane coating, and thereafter curing said rubber compound.

25. The method of claim 24, further comprising the step of drying said silane coating prior to applying said uncured rubber compound.

26. A metal substrate having rubber adhered thereto made in accordance with the method of claim 1.

Patentansprüche

1. Verfahren zum Kleben von Gummi auf ein Metallsubstrat, umfassend:

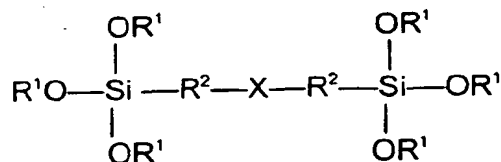
(a) Auftragen einer Beschichtung von einer Silanzusammensetzung auf ein Metallsubstrat, wobei die Silan-

zusammensetzung umfasst:

- ein Bissilylaminosilan oder das Hydrolysat oder das teilweise Hydrolysat davon und
- ein Bissilylpolyschwefelsilan oder das Hydrolysat oder das teilweise Hydrolysat davon und

(b) Aufkleben des Gummis/Kautschuks auf die Beschichtung.

2. Verfahren nach Anspruch 1, worin das Bissilylaminosilan ein Aminosilan mit zwei trisubstituierten Silylgruppen umfasst, worin die Substituenten einzeln ausgewählt sind aus der Gruppe bestehend aus Alkoxy, Aryloxy und Acyloxy.
3. Verfahren nach Anspruch 2, worin das Bissilylaminosilan



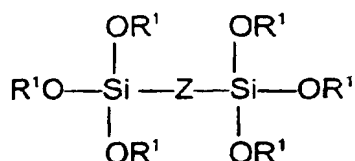
umfasst, worin:

- jedes R¹ einzeln ausgewählt ist aus der Gruppe bestehend aus C₁-C₂₄-Alkyl und C₂-C₂₄-Acyl,
- jedes R² einzeln ausgewählt ist aus der Gruppe bestehend aus substituierten aliphatischen Gruppen, unsubstituierten aliphatischen Gruppen, substituierten aromatischen Gruppen und unsubstituierten aromatischen Gruppen und
- X entweder:



- ist,
- worin jedes R³ einzeln ausgewählt ist aus der Gruppe bestehend aus Wasserstoff, substituierten und unsubstituierten aliphatischen Gruppen und substituierten und unsubstituierten aromatischen Gruppen und
- R⁴ ausgewählt ist aus der Gruppe bestehend aus substituierten und unsubstituierten aliphatischen Gruppen und substituierten und unsubstituierten aromatischen Gruppen.

4. Verfahren nach Anspruch 3, worin R¹ jeweils einzeln ausgewählt ist aus der Gruppe bestehend aus Ethyl, Methyl, Propyl, Isopropyl, Butyl, Isobutyl, sek.-Butyl, tert.-Butyl und Acetyl.
5. Verfahren nach Anspruch 3, worin X ausgewählt ist aus der Gruppe bestehend aus einer C-Si-Bindung, C₁-C₆-Alkylen, C₁-C₆-Alkenylen, C₁-C₆-Alkylen, substituiert mit mindestens einer Aminogruppe, C₁-C₆-Alkenylen, substituiert mit mindestens einer Aminogruppe, Arylen und Alkylarylen.
6. Verfahren nach Anspruch 3, worin R² jeweils einzeln ausgewählt ist aus der Gruppe bestehend aus Wasserstoff, Ethyl, Methyl, Propyl, Isopropyl, Butyl, Isobutyl, sek.-Butyl, tert.-Butyl und Acetyl.
7. Verfahren nach Anspruch 1, worin das Bissilylaminosilan ausgewählt ist aus der Gruppe bestehend aus Bis(triethoxysilylpropyl)amin, Bis(triethoxysilylpropyl)amin und Bis(triethoxysilylpropyl)ethylendiamin.
8. Verfahren nach Anspruch 1, worin das Bissilylpolyschwefelsilan



umfasst, worin R¹ jeweils eine Alkyl- oder eine Acetylgruppe ist und Z -Q-S_x-Q ist, worin Q jeweils eine aliphatische oder aromatische Gruppe ist und x eine ganze Zahl von 2 bis 10 ist.

9. Verfahren nach Anspruch 8, worin R¹ jeweils einzeln ausgewählt ist aus der Gruppe bestehend aus Ethyl, Methyl, Propyl, Isopropyl, Butyl, Isobutyl, sek.-Butyl, tert.-Butyl und Acetyl.
10. Verfahren nach Anspruch 8, worin Q jeweils einzeln ausgewählt ist aus der Gruppe bestehend aus C₁-C₆-Alkyl (linear oder verzweigt), C₁-C₆-Alkenyl (linear oder verzweigt), C₁-C₆-Alkyl, substituiert mit einer oder mehreren Aminogruppen, C₁-C₆-Alkenyl, substituiert mit einer oder mehreren Aminogruppen, Benzyl und Benzyl, substituiert mit C₁-C₆-Alkyl.
11. Verfahren nach Anspruch 1, worin das mindesten eine Bissilylpolyschwefelsilan ein Bis(triethoxysilylpropyl)sulfid mit 2 bis 10 Schwefelatomen umfasst.
12. Verfahren nach Anspruch 11, worin das mindestens eine Bissilylpolyschwefelsilan Bis(triethoxysilylpropyl)tetra-sulfid umfasst.
13. Verfahren nach Anspruch 1, worin das Metallsubstrat ausgewählt ist aus der Gruppe bestehend aus:
 - Zink und Zinklegierungen,
 - Metallsubstraten mit einem zinkhaltigen Überzug,
 - Stahl,
 - Aluminium und Aluminiumlegierungen,
 - Kupfer und Kupferlegierungen,
 - Magnesiumlegierungen,
 - Zinn- und Zinnlegierungen und
 - Metallsubstraten mit zinnhaltigen Überzügen.
14. Verfahren nach Anspruch 1, worin die Silane in der Silanzusammensetzung im wesentlichen nicht hydrolysiert sind.
15. Verfahren nach Anspruch 14, worin das Verhältnis von Bissilylaminosilanen zu Bissilylpolyschwefelsilanen in der Silanzusammensetzung zwischen 1:10 und 10:1 liegt.
16. Verfahren nach Anspruch 14, worin die Silanzusammensetzung ferner ein nicht wäßriges Lösungsmittel umfasst.
17. Verfahren nach Anspruch 1, worin die Silanzusammensetzung im wesentlichen aus dem mindestens einen im wesentlichen nicht hydrolysierten Bissilylaminosilan und dem mindestens einen im wesentlichen nicht hydrolysierten Bissilylpolyschwefelsilan besteht.
18. Verfahren nach Anspruch 1, worin die Silane in der Silanzusammensetzung mindestens teilweise hydrolysiert sind.
19. Verfahren nach Anspruch 18, worin das Verhältnis von Bissilylaminosilanen zu Bissilylpolyschwefelsilanen in der Silanzusammensetzung zwischen 1:10 und 10:1 liegt.
20. Verfahren nach Anspruch 19, worin die Silanzusammensetzung ferner Wasser und ein Lösungsmittel umfasst.
21. Verfahren nach Anspruch 20, worin das Verhältnis von Wasser zu Lösungsmittel in der Silanzusammensetzung zwischen 1:1 und 1:20 liegt.
22. Verfahren nach Anspruch 18, worin der pH-Wert der Silanzusammensetzung zwischen 4 und 7 liegt.

23. Verfahren nach Anspruch 1, worin das Gummi einen schwefelvulkanisierten Kautschuk umfasst.

24. Verfahren nach Anspruch 23, worin der Schritt des Anklebens des schwefelvulkanisierten Kautschuks das Auftragen eines unvulkanisierten Kautschukcompounds direkt auf die Silanbeschichtung und danach das Vulkanisieren des Kautschukcompounds umfasst.

25. Verfahren nach Anspruch 24, das ferner den Schritt der Trocknung der Silanbeschichtung vor dem Auftragen des unvulkanisierten Kautschukcompounds umfasst.

26. Metallsubstrat mit einem daran geklebten Gummi hergestellt nach dem Verfahren von Anspruch 1.

Revendications

1. procédé permettant au caoutchouc d'adhérer à un substrat en métal, comprenant

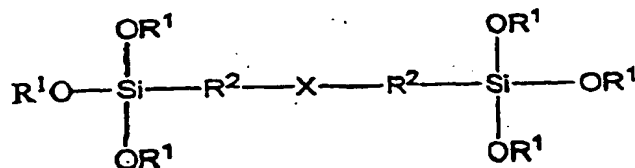
(a) l'application d'un revêtement d'une composition de silane sur un substrat en métal, ladite composition comprenant :

- un aminosilane bis-silyle ou l'hydrolysate ou l'hydrolysate partiel de celui-ci ;
- un silane polysulfure bis-silyle ou l'hydrolysate ou l'hydrolysate partiel de celui-ci ; et

(b) l'adhérence du caoutchouc au dit revêtement.

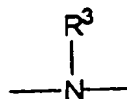
2. Procédé selon la revendication 1, dans lequel l'aminosilane bis-silyle comprend un aminosilane ayant deux groupes silyles trisubstitués, dans lequel les substituants sont choisis de manière individuelle dans le groupe comprenant l'alcoxy, l'aryloxy et l'acyloxy.

3. Procédé selon la revendication 2, dans lequel ledit aminosilane bis-silyle comprend

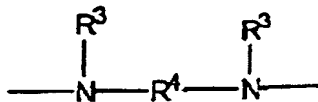


dans laquelle

- chaque R¹ est choisi de manière individuelle dans le groupe comprenant : l'alkyle en C₁ - C₂₄ et l' acyle en C₂ - C₂₄
- chaque R² est choisi de manière individuelle dans le groupe comprenant : des groupes aliphatiques substitués, des groupes aliphatiques non substitués, des groupes aromatiques substitués et un groupe aromatique non substitué ; et
- X est soit :



soit



où

- chaque R^3 est choisi de manière individuelle dans le groupe comprenant : de l'hydrogène, des groupes aliphatiques substitués et non substitués, et des groupes aromatiques substitués et non substitués ; et
- chaque R^4 est choisi de manière individuelle dans le groupe comprenant : des groupes aliphatiques substitués, et non substitués, et des groupes aromatiques substitués et non substitués.

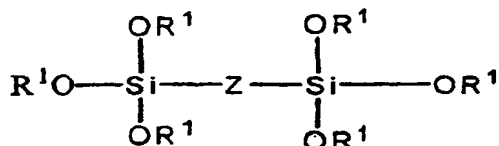
4. Procédé selon la revendication 3, dans lequel R^1 est choisi de manière individuelle dans le groupe comprenant : l'éthyle, le méthyle, le propyle, l'iso-propyle, le butyle, l'iso-butyle, le sec-butyle, le ter-butyle et l'acétyle.

5. Procédé selon la revendication 3, dans lequel X est choisi de manière individuelle dans le groupe comprenant : une liaison C-Si, un alkylène en $\text{C}_1 - \text{C}_6$, un alcényle en $\text{C}_1 - \text{C}_6$, un alkylène en $\text{C}_1 - \text{C}_6$, substitué avec au moins un groupe amino, un alcényle en $\text{C}_1 - \text{C}_6$ substitué avec au moins un groupe amino, un arylène et un alkylarylene.

6. Procédé selon la revendication 3, dans lequel R^2 est choisi de manière individuelle dans le groupe comprenant : l'hydrogène, l'éthyle, le méthyle, le propyle, l'iso-propyle, le butyle, l'iso-butyle, le sec-butyle, le ter-butyle et l'acétyle.

7. Procédé selon la revendication 1, dans lequel ledit aminosilane bis-silyle est choisi dans le groupe comprenant du : bis-(triméthoxysilylpropyl)amino, bis-(triéthoxysilylpropyl)amino, et de la diamine de bis-(triéthoxysilylpropyl)éthylène.

8. Procédé selon la revendication 1, dans lequel le silane polysulfure de bis-silyle comprend :



où chaque R^1 est un groupe alkyle ou un groupe acétyle et Z est $\text{---Q---S}_x\text{---Q---}$ où chaque Q est un groupe aliphatique ou aromatique et x est un nombre entier de 2 à 10.

9. Procédé selon la revendication 8, dans lequel R^2 est choisi de manière individuelle dans le groupe comprenant : l'éthyle, le méthyle, le propyle, l'iso-propyle, le butyle, l'iso-butyle, le sec-butyle, le ter-butyle et l'acétyle.

10. Procédé selon la revendication 8, dans lequel chaque Q est choisi de manière individuelle dans le groupe comprenant un alkyle en $\text{C}_1 - \text{C}_6$ (linéaire ou ramifié), un alcényle en $\text{C}_1 - \text{C}_6$ (linéaire ou ramifié), un alkyle en $\text{C}_1 - \text{C}_6$ substitué avec un ou plusieurs groupes amino, un alcényle en $\text{C}_1 - \text{C}_6$ substitué avec un ou plusieurs groupes amino, du benzyle et du benzyle substitué avec de l'alkyle en $\text{C}_1 - \text{C}_6$.

11. Procédé selon la revendication 1, dans lequel ledit au moins un silane polysulfure bis-silyle comprend du sulfure de bis-(triéthoxysilylpropyl) ayant 2 à 10 atomes de soufre.

12. Procédé selon la revendication 11, dans lequel ledit au moins un silane polysulfure bis-silyle comprend du tétra-sulfure de bis-(triéthoxysilylpropyl).

13. Procédé selon la revendication 1, dans lequel ledit substrat en métal est choisi dans le groupe comprenant :

- du zinc et des alliages de zinc ;

- des substrats en métal ayant un revêtement contenant du zinc ;
- de l'acier ;
- de l'aluminium et des alliages d'aluminium ;
- du cuivre et des alliages de cuivre ;
- des alliages de magnésium ;
- de l'étain et des alliages d'étain ; et
- des substrats métalliques ayant des revêtements contenant de l'étain.

14. Procédé selon la revendication 1, dans lequel les silanes dans ladite composition silane sont essentiellement non hydrolysés.

15. Procédé selon la revendication 14, dans lequel le rapport des aminosilanes bis-silyles par rapport aux silanes polysulfures bis-silyles dans ladite composition de silane se situe entre 1:10 et 10:1.

16. Procédé selon la revendication 14, dans lequel la composition de silane comprend par ailleurs un solvant non aqueux.

17. Procédé selon la revendication 1, dans lequel ladite composition de silane se compose dudit au moins un aminosilane bis-silyle essentiellement non hydrolysé et dudit au moins un silane polysulfure bis-silyle essentiellement non hydrolysé.

18. Procédé selon la revendication 1, dans lequel les silanes dans ladite composition silane sont au moins en partie hydrolysés.

19. Procédé selon la revendication 18, dans lequel le rapport des aminosilanes bis-silyles par rapport aux silanes polysulfures bis-silyles dans ladite composition de silane se situe entre 1:10 et 10:1.

20. Procédé selon la revendication 19, dans lequel ladite composition de silane comprend par ailleurs de l'eau et un solvant.

21. Procédé selon la revendication 20, dans lequel le rapport de l'eau par rapport au solvant dans ladite composition de silane se situe entre 1:1 et 1:20.

22. Procédé selon la revendication 18 dans lequel le pH de ladite composition de silane se situe entre 4 et 7.

23. Procédé selon la revendication 1, dans lequel ledit caoutchouc comprend un caoutchouc vulcanisé au soufre.

24. Procédé selon la revendication 23, dans lequel ladite étape d'adhérence dudit caoutchouc vulcanisé au soufre comprend l'application un composé en caoutchouc non vulcanisé directement sur ledit revêtement de silane et ensuite la vulcanisation dudit composé caoutchouc.

25. Procédé selon la revendication 24, comprenant par ailleurs l'étape de séchage dudit revêtement de silane avant l'application dudit composé caoutchouc non vulcanisé.

26. Substrat en métal ayant un caoutchouc ayant adhéré à celui-ci réalisé conformément au procédé selon la revendication 1.

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